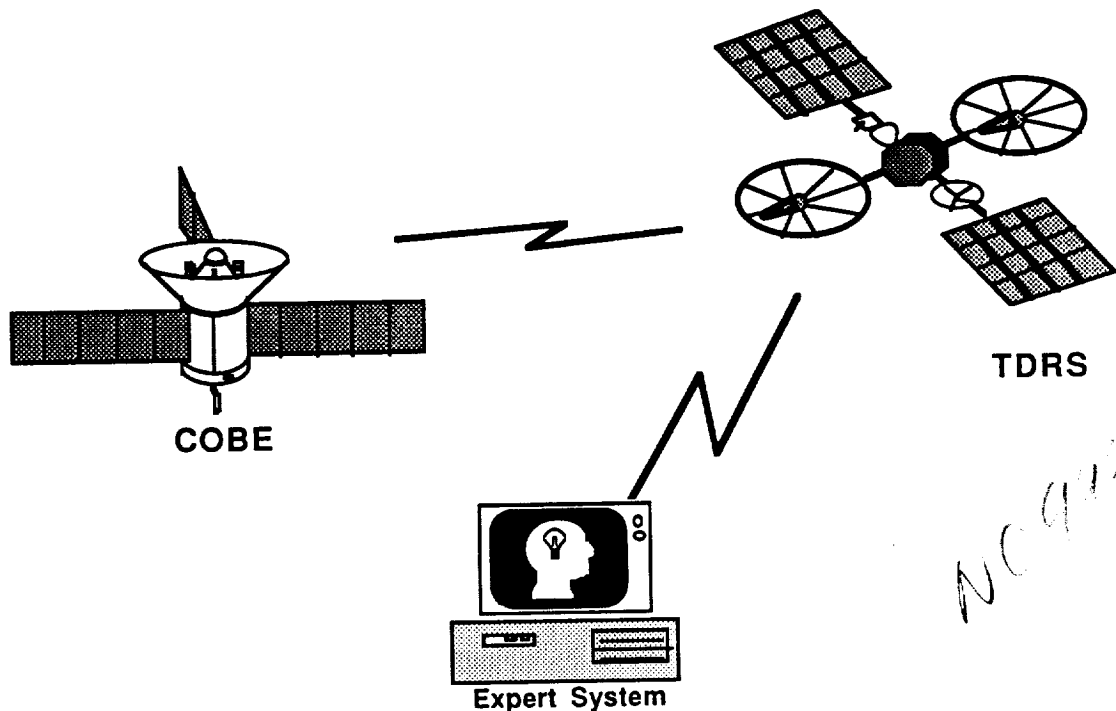


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CLEAR

Communications Link Expert Assistance Resource



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ABSTRACT

Communications Link Expert Assistance Resource (CLEAR) is a real time, fault diagnosis expert system for the Cosmic Background Explorer (COBE) Mission Operations Room (MOR). The CLEAR expert system is an operational prototype which assists the MOR operator/analyst by isolating and diagnosing faults in the spacecraft communication link with the Tracking and Data Relay Satellite (TDRS) during periods of realtime data acquisition.

This paper discusses the mission domain, user requirements, hardware configuration, expert system concept, tool selection, development approach, and system design. Development approach and system implementation are emphasized. Also discussed are system architecture, tool selection, operation, and future plans.

INTRODUCTION

The Communications Link Expert System Resource (CLEAR) is an expert system to be implemented and demonstrated for the Cosmic Background Explorer (COBE) Payload Operations Control Center (POCC) as a joint project between the Mission Operations Division and the Data Systems Technology Division within the Mission Operations and Data Systems Directorate at Goddard Space Flight Center. The purpose of this joint project is to design and implement an expert system to monitor and isolate faults of the COBE and Tracking and Data Relay Satellite (TDRS) communications link and to provide advice to correct these faults.

BACKGROUND

NASA's Tracking and Data Relay Satellite System (TDRSS) has placed the responsibility of configuring, monitoring and troubleshooting many types of spacecraft communications upon the analysts at the consoles in the realtime environment of the POCC. The result is a complex task which, if not handled quickly and properly, can result in poor utilization of TDRSS services, inefficient spacecraft operations and potential hazards to spacecraft health and safety.

Operating the spacecraft communications links with the TDRS requires realtime evaluation of a mission oriented subset of more than 100 configuration and performance parameters and requires knowledge of both TDRSS services and spacecraft communications systems. This evaluation of realtime data must be correlated with an understanding of these services and systems both to isolate problems and to select appropriate courses of action to resolve identified problems.

At present, extensive training and

communication of actual experience are used to develop MOR analyst capabilities to the fullest. Regardless, the size of the task places a large burden on the operator. It is the objective of automation, specifically utilization of an expert system acting as an advisor, to produce a more reliable, more efficient and less error prone system of operations.

Spacecraft communication links with the Tracking and Data Relay Satellite and TDRSS services are used routinely and by many missions. This gives the CLEAR system a very high utility, particularly if only minor modifications are needed to allow other missions to use the system.

The rationale for choosing the COBE spacecraft communication links as the domain was timeliness. Ground system preparation for the mission including acquisition of MOR equipment was just starting at the time of the decision to develop the expert system. This equipment included computer workstations of sufficient power to support an expert system and the designers felt that one workstation would normally be available during operational periods.

MISSION DOMAIN

The COBE, a single observatory mission in the area of astrophysics and specifically cosmology, will be launched in early 1989 and placed in a 900-km altitude, circular Sun-synchronous terminator (twilight) orbit. The COBE will use the TDRSS single access (SSA) S-band service for nominal on-orbit tracking, command, and telemetry support.

The COBE ground system will acquire data via both the Ground Network (GN) and the Space Network (SN). The GN will provide the interface to the COBE POCC and the Sensor Data Processing Facility (SPDF)

for the COBE science dump data. The SN will provide realtime data acquisition, command interface and tracking.

The Flight Operations Team (FOT), operating from the COBE POCC, will perform and participate in mission planning, realtime telemetry evaluation, off-line in-depth analysis, COBE-unique data base inputs, and assist in discrepancy and enhancement reporting, software testing, experiment-scientist interfaces, command management and generation, orbit and attitude-data coordination and data accountability.

COBE realtime operations will consist of four or five 20-minute TDRSS SSA forward and return events per day and will be used for uplinking stored commands, ranging, time management, and observatory safety and health monitoring. The CLEAR will support these periods of realtime operations.

The COBE POCC will be located in the Multi-Satellite Operations Control Center (MSOCC). A dedicated COBE Mission Operations Room (MOR) will be provided. Telemetry data from TDRSS or the ground receiving station will enter MSOCC via Nascom circuits. The data will enter the Telemetry and Command (TAC) computer and processed in the Application Processor (AP) computer for display at keyboard CRT's in the MOR.

The COBE Project Flight Operations Team performs the function of controlling the COBE satellite. MOR facility requirements include console facilities for three operations positions. One of the three positions will be used for CLEAR.

USER REQUIREMENTS

The following are the functional and performance requirements specifications

for the Communications Link Expert Assistance Resource. The information herein was extracted by the CLEAR knowledge engineers working with available TDRSS and COBE documentation and with the domain expert.

To carry out its task, the CLEAR system will perform the following five functions:

- Data Conversion,
- Configuration Checking,
- Communication Link Monitoring,
- Fault Diagnosis, and
- Event Logging.

CLEAR is to have no effect upon the COBE POCC processing systems and is to be transparent to other MSOCC systems. The CLEAR system will be a strictly passive component of the system supporting COBE realtime operations.

CLEAR is to be transportable within the MOR. The system will run on any Engineering Analysis Workstation (EAW) in the COBE POCC without hardware modification and with the same operating system level software, e.g. communication package, graphics routines and device drivers, used by other application programs.

CLEAR is to use a standard communication package to be developed for POCC workstation applications. The data furnished by the AP will be ordered (positional not keyword) ASCII text (alphanumeric not binary). The system will extract the TDRSS performance data Operations Data Messages (ODM) and spacecraft status parameters from the communication buffer and convert them to the internal format required by the expert system.

COBE and TDRSS configuration parameters

for the scheduled event are to be set at initialization of the expert system. The CLEAR system will allow the operator to input values for configuration parameters, current date and clock time. The system will log the configuration parameters for the event. These parameters will be utilized by CLEAR to check for the start of the event and for the correct event configuration and will notify the analyst of any discrepancy.

The analyst is to be able to correct the data if the error lies in the CLEAR configuration parameters rather than in the COBE or TDRSS configuration. After the corrected data has been entered, the expert system can be reset and restarted.

CLEAR is to be driven by ODM and status data sent by the AP. The system will monitor the input data (communication buffer arrival) frequency and will warn the analyst if input is not received within the expected (4 to 5 second) interval. The expert system will monitor the communications link parameter values to detect and isolate faults.

CLEAR is to diagnose the faults identified during an event. The system will determine possible sources or causes of a fault, rank multiple possibilities in order of probability and present the result to the analyst. The system will also recommend course(s) of action that might be taken by the analyst. If requested, the system will explain the reasoning used to diagnose a fault and recommend a course of action.

CLEAR is to log all expert system activity for post event analysis. The system will time tag all identified faults and will record the inferences, the diagnoses, the recommendations offered and the actions taken as (and if) indicated by the analyst. The system will provide non-realtime utilities to print a formatted

copy of the log, to trace and analyze the activity of the expert system during the event and to extract statistics for evaluation of system performance.

CLEAR is to operate in realtime with a performance requirement derived from the expected 3 to 7 second communication buffer (input data) arrival frequency. The expert system will convert input data, check parameter values and perform inferences within this time interval. Event logging, operator dialog and explanations are not realtime events subject to the performance requirement.

HARDWARE CONFIGURATION

The computer on which the CLEAR will run will be any one of the three workstations being used for console operations in the COBE MOR. These workstations are IBM AT compatible personal computers that attach to the POCC communications network as workstations which receive a composite of operator display screens. The configuration of these AT compatible personal computers is as follows:

- Kandi AT running at 8 mHz clock speed,
- Dolen DC-4 (to be upgraded to DC-8, when available) Video Board supporting RS-170A,
- 30 MByte hard disk,
- 1.2 MByte and 360 KByte floppy disk drives,
- 1.5 MByte AST Advantage Memory Board,
- 4 RS-232 communications ports,
- 1 parallel port, and
- Color display compatible of 640 x 480 pixels in 8 colors.

This configuration will support the Intelligent Systems Corporation (ISC) video format for compatibility with MSOCC and the POCC display systems.

The Kandl AT is configured with 512 KBytes of internal RAM with an additional 1.5 MBytes of Extended Memory RAM available on the AST advantage card. Although there is a 640 KByte addressable memory limit of PC-DOS 3.1, the 1.5 MByte AST Advantage Memory Card can be configured as a RAM disk and used for storing data buffers, or as a repository for other executable code that could be swapped into the DOS memory area on demand.

The Kandl AT will contain a 30 MByte hard (fixed) disk for storage use. The operating system and other support programs are predicted to occupy approximately 10-15 MBytes of disk storage. This leaves ample storage for the entire CLEAR application and supporting files which are predicted to be less than one MByte of disk storage. The amount of memory required by the CLEAR Event Log is not included in this figure as it is presently not known how much storage will be required.

EXPERT SYSTEM CONCEPT

The CLEAR expert system is to assist the analyst in the MOR in operating the COBE spacecraft communication links with the TDRS. The following functions are to be performed by the system:

- monitor the spacecraft communication data,
- isolate suspected faults for analysis,
- diagnose actual faults,
- determine the set of alternative actions,

- rank and display the possible responses for the analyst,

- explain the diagnosis, the selection of alternatives and the ranking of possible responses, and

- activate the operator selected response (future enhancement not part of initial prototype).

Two very significant requirements are the "realtime" response required of the expert system and the mandatory requirement that the effect of the CLEAR on the operational system be either nil or minimal. These two requirements considered together have generated the concept of the CLEAR expert system prototype attached to the operational system as if it were an operator's workstation display. This approach, rather than that an embedded or inline system, is expected to reduce the effect of the prototype expert system on the operational system to the minimum and to meet the response requirement.

TOOL SELECTION

The realtime response required of the CLEAR system translates into a performance requirement for the expert system. The data driven and diagnostic nature of the expert system place interface and inference logic requirements on the tool selected to build the application. Further selection criteria come from the hardware and software compatibility requirements. The CLEAR must run on the POCC workstation which is an IBM AT compatible personal computer and must use operating system level software written in C and compiled under Microsoft® C Version 4.0.

A number of secondary (desireable rather than mandatory) requirements are also used in the selection including cost,

number of tool users, length of tool usage, stability of supplier, development environment and availability of source code. The secondary selection criteria are used to rank the expert system building tools that satisfy the mandatory requirements.

Although several commercially available expert system building tools meet the mandatory requirements based upon available information including independent benchmark tests, product reviews and reported user experience in using these products, none is ranked higher than a NASA expert system building tool, CLIPS.

CLIPS, a tool for the development of expert systems, was created by the Artificial Intelligence Section of the Mission Planning and Analysis Division at NASA/Johnson Space Center. CLIPS provides an inference engine and language syntax which provides the framework for the construction of rule-based systems.

CLIPS was entirely developed in C for performance and portability. The key features of CLIPS are:

- Forward Chaining Rules
- Powerful Rule Syntax: CLIPS allows free form patterns, single and multi-field variable bindings across patterns, user defined predicate functions on the LHS of a rule, and other powerful features.
- Portability: CLIPS has been installed on over half a dozen machines with little or no code changes.
- High Performance: CLIPS' performance on minicomputers (VAX, SUN) is comparable to the performance of high powered expert system tools in those environments. On microcomputers, CLIPS outperforms most other microcomputer based tools.

- Embeddable: CLIPS systems may be embedded within other C programs and called as a subroutine.

- Interactive Development: CLIPS provides an interactive, text oriented development environment, including debugging aids.

- Completely Integrated With C: Users may define and call their own functions from within CLIPS.

- Extensible: CLIPS may be easily extended to add new capabilities.

- Source Code: CLIPS comes with all source code and can be modified or tailored to meet a specific users' needs.

- Fully Documented: CLIPS comes with a full reference manual complete with numerous examples of CLIPS syntax. Examples are also given on how to create user defined functions and CLIPS extension. A User's Guide to introduce expert system programming with CLIPS is also available.

CLIPS is available through:

Computer Software Management and
Information Center (COSMIC)
NASA Software Dissemination Center
University of Georgia
Athens, Georgia.

DEVELOPMENT APPROACH

The CLEAR system is being implemented in three phases. The first phase, which was completed February 28, 1987, was the rapid prototyping phase. The prototype was developed on a Symbolics 3640 Lisp Machine using the Automated Reasoning Tool (ART). The first phase demonstrated the expert system technology and an understanding of the problem domain using an advanced development environment. The products of this phase that transfer to the next are the user

interface and the knowledge base.

The second phase of implementation is the operational prototyping phase. This operational prototype is being developed on the Kandl AT using CLIPS and the Microsoft® C 4.0 compiler. In this phase, the CLEAR team will evaluate hardware and software performance, and locate problems using the actual operational environment driven by simulated operational data. In addition to the early determination and resolution of problems, the knowledge base is being enhanced and the entire system will transfer to the final phase.

The third and final phase of the CLEAR system implementation is the installation in the COBE MOR of the hardware and software developed in the second phase. Deferred components and enhancements stemming from the second phase will be developed at this time. This operational prototype will be integrated, tested and available to assist the MOR operator/analyst during COBE operations.

During the first two phases, CLEAR receives simulated data from a locally written Data Simulator. The simulator transmits data resembling the data that CLEAR will receive from the MSOCC Applications Processor after installation and integration in the third phase. The

CLEAR team developed the Data Simulator to allow testing and debugging of the expert system without having to wait for simulated test data in the last phase.

The Data Simulator is a software program that resides on a VAX 8600. This design prevents the simulator from interfering with the processing time of the computer on which CLEAR is running. The design also allows the simulator to be used to test CLEAR on both the Symbolics 3640 in the first phase and the Kandl AT in the second without rewriting or transporting the software program.

In the third phase, CLEAR will have a physical interface with the MSOCC Applications Processor (AP).

SYSTEM ARCHITECTURE

The CLEAR system software architecture consists of the *Expert System* and two *Interface Subsystems* (Figure 1).

The *Expert System* is a forward-chaining, rule-based system. It is implemented using the C Language Integrated Production System (CLIPS), an expert system development tool developed by Johnson Space Center. CLIPS was chosen because it is forward-chaining, portable, and supports integration of external functions written in the

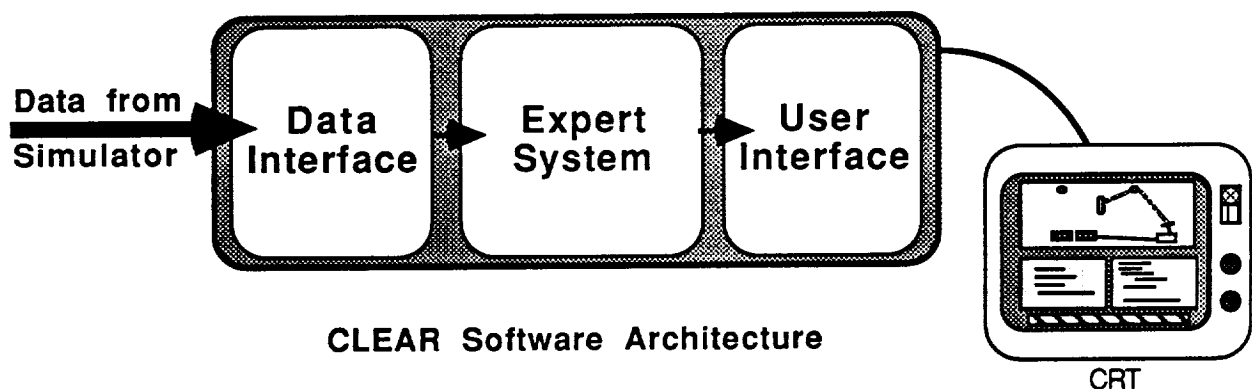


Figure 1

programming language 'C'.

The *User Interface* subsystem interfaces the user's CRT display to the Expert System. This subsystem generates all of the text and graphics to be displayed to the user on the CRT. Independently developed Video Interface Routines are utilized by this subsystem to produce the screen display.

The *Data Interface* subsystem interfaces the Expert System to the Applications Processor in the Multi-Satellite Operations Control Center (MSOCC). This subsystem buffers the ODM and spacecraft status parameters received from the AP utilizing the workstation's communications interface software which is being developed independently. The

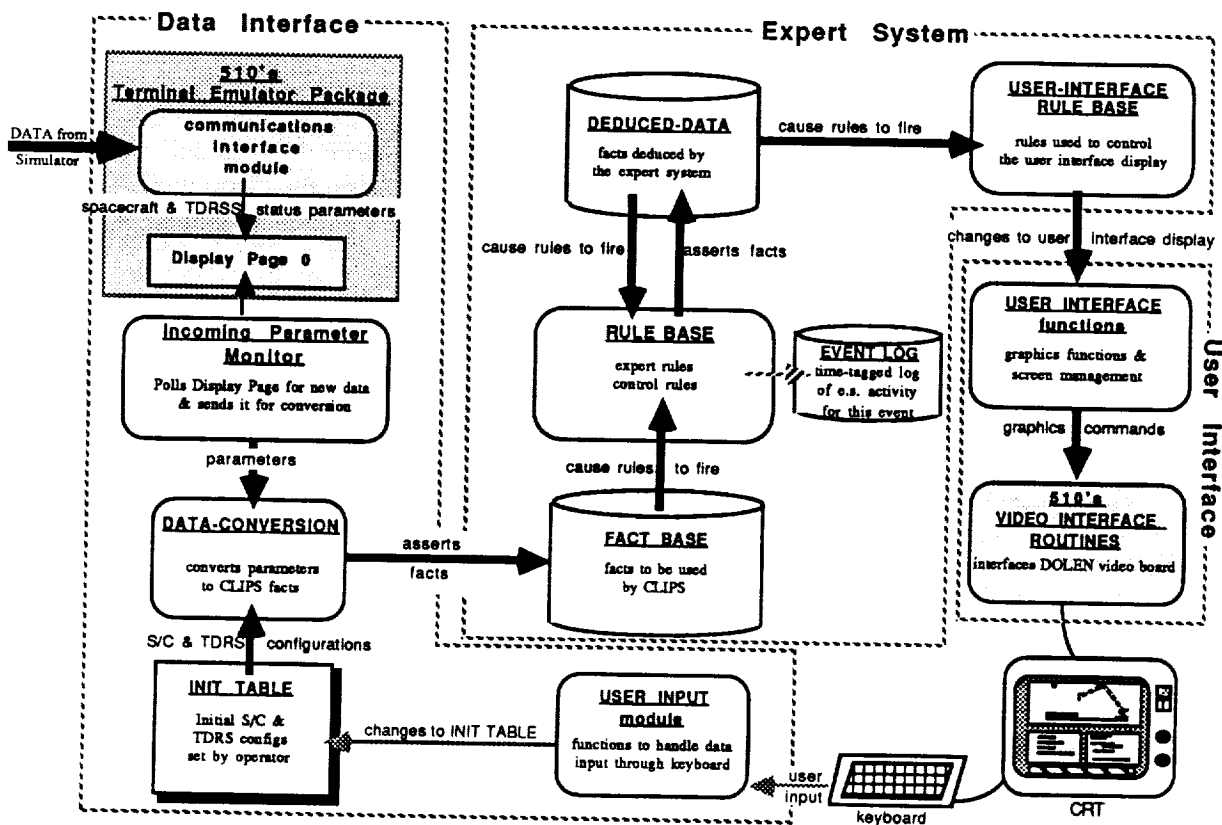
buffered data is then converted to the format required by the Expert System and passed to it.

These three primary subsystems of the CLEAR system can be further broken down into their functional modules (Figure 2).

Expert System

The Expert System consists of fact bases, a rule bases, an *Inference Engine* and an *Event Log*.

Data enters the Expert System as CLIPS facts asserted by the *Data-Conversion* routine. Each fact represents a piece of information which has been asserted into the *Fact Base* or *Deduced-Data* base. In CLIPS, the Fact Base is properly called a "Fact-List" and the existence or non-



CLEAR Functional Design (phase 2)

Figure 2

existence of facts in this list causes rules in the *Rule-Base* to fire. The actions of rules can cause facts to be asserted in or retracted from both the Deduced-Data base and the Fact Base.

The *Event Log* is a log of all Expert System activity for post-event analysis. The system time tags all identified faults and records the inferences, diagnoses, and recommendations offered to the analyst. The system provides non-realtime utilities to print a formatted copy of the log, to trace and analyze the activity of the inference during the event, and to extract statistics for evaluation of system performance.

The *Deduced-Data* base is a list of facts that are deduced by the Expert System, such as the status of the links and control information. These facts cause rules in the User-Interface Rule Base to fire which, in turn, sends function calls to the User Interface subsystem.

User Interface

The *User Interface Functions* manage the screen display. These functions utilize the *Video Interface Routines* that are being independently developed to drive the Dolen DC-4 (and, subsequently, the DC-8) video board.

Data Interface

The ODM and spacecraft status parameters coming from the AP will be formatted by the *Terminal Emulator* package for viewing upon the workstations' CRT by the FOA. The Terminal Emulator package functionally processes the incoming data as follows.

The parameters enter the POCC workstation through the communications port and are stored in a circular character buffer. Every 30 milliseconds (30 μ -

sec), a process checks this buffer for newly arrived data. When a parameter arrives, this process first decodes its value, attributes and screen coordinates, and then stores them in a video buffer named *Display Page 0* (zero).

The *Incoming Parameter Monitor* will poll the Display Page 0 for the new parameters and will send them to *Data-Conversion* when located. Data-Conversion converts these parameters to the corresponding CLIPS facts and asserts them into the Expert System.

A second source of input data is the Initialization Table. This table contains COBE spacecraft and TDRS configuration parameter values. When first set or when modified, these values are sent to Data-Conversion to be converted to the appropriate CLIPS format. If parameters in the Initialization Table are modified during an event, CLEAR can be reset and restarted using these modified values.

The Expert System, written in CLIPS, was the first subsystem to be coded. The coding process was straightforward due to the similarities between CLIPS and ART (in which the phase one prototype was written). The User Interface was the second subsystem to be developed. A highly functional user interface assisted in developing knowledge base because it was only through the CRT display that the capabilities of the expert system could be demonstrated to the "expert" for approval or refinement. The Data Interface was the final subsystem to be coded. Both the Data Interface and the User Interface subsystems were coded in Microsoft® C 4.0.

OPERATION

As a data-driven expert system, CLEAR receives ODM and status data from the AP in realtime, monitors the data, advises

the FOT of problems and recommends possible solutions for each problem isolated. To facilitate greater acceptance and ease of use, user input is minimal.

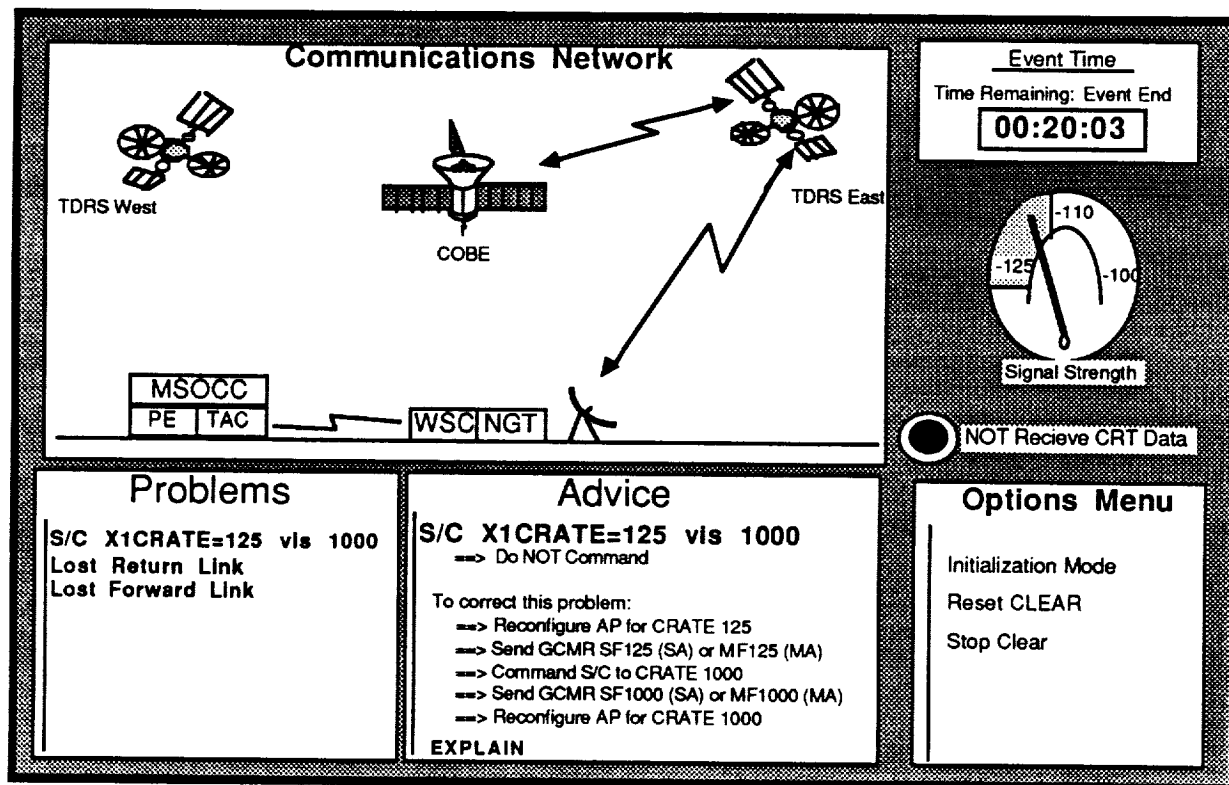
The only user input required by CLEAR is the pre-event initialization of parameters in the Initialization Table. Default settings for each spacecraft and ground system parameter are provided along with an override via keyboard entry.

During a pass, the parameter values of the Initialization Table can be modified by the Flight Operations Analyst (FOA) if the expert system detects and notifies him/her of anomalies between these parameters and the actual COBE or TDRS configuration. The FOA may then reset and restart the expert system using the corrected parameters.

If, on the other hand, the user notices an incorrect value in the Initialization Table before the expert system isolates it, a correction can be made without affecting the Data Interface software or the functioning of the expert system.

CLEAR outputs to the CRT of the workstation. Figure 3 shows the screen display of the user interface of the CLEAR first phase prototype which was developed on the Symbolics 3640. Due to the differences in graphics capabilities between the Symbolics and the Kاندل AT, the actual screen display developed in the second phase may be different; however, the CLEAR team will strive to develop a screen display as similar as the graphic routines will efficiently permit.

The display has a COBE-POCC network graphic, "Problem" and "Advice" message



CLEAR User Interface Design
Figure 3

areas, and various graphic indicators which are used for continual display of the time and other important parameters. The "Problem" and "Advice" message areas remain blank until the need for a message is determined by the Expert System, at which time the problem and the appropriate advice are displayed. The "Problem" area displays all the problems isolated, prioritized by the most likely initial cause. The "Advice" area provides recommendations on how to correct the most critical problem of the "Problem" area. In the case of multiple advice options, the first one listed is the best option, followed by other advice in descending order of probable effectiveness.

The COBE-POCC network graphic shown in Figure 3 consists of two TDRS spacecraft, the COBE spacecraft, and the NGT/WSGT and MSOCC boxes. When solid lock on COBE is achieved, there are two green lines (each line denotes both the forward and return links); one from COBE to the appropriate TDRS, and one from TDRS to WSGT. If data indicates that there is a problem with either of these links, the troubled link will turn red and flash while the other healthy link remains green.

FUTURE PLANS

The second phase, implementation of an operational prototype on the EAW, will be finished in the Fall of 1987. The third phase will begin at that time and will

include the following tasks:

- implementation of deferred modules,
- addition of enhancements identified in the second phase,
- generation of system documentation,
- generation of training manuals,
- delivery and installation of the CLEAR prototype in the MOR,
- system integration, and
- system test and acceptance by the user.

One additional task, the system performance evaluation, must be deferred until COBE is launched and a baseline of operational experience has been obtained. This task is to evaluate both the efficiency of the system and the effectiveness of CLEAR in assisting the operator in the MOR.

ACKNOWLEDGEMENTS

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